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synchronous rectifier,
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UTILIZATION OF FULL BRIDGE CONVERTER WITH SYNCHRONOUS RECTIFIER FOR ELECTROPLATING

This paper deals with utilization of full bridge converter with synchronous rectifier for electroplating. Main focus of the paper is on minimization of conduction losses. In paper the diode rectifier losses and synchronous rectifier losses and efficiency are compared. The experimental verifications show better efficiency of synchronous rectifier which is shown on graph and thermal images of both types of devices at the end of the paper.

1. INTRODUCTION

Switching power supplies for electroplating processes are characterized by low output voltage (tens of volts), which is comparable to the voltage drop of rectifying elements and large current output (thousands of amps). Permissible output current ripple is 2-5% of the average current. Ripple of the output voltage is 1%. Significant losses are caused by current flow through semiconductor structure for required parameters.

The goal of research is minimizing the switching power supply losses using of synchronous rectifier. It is necessary to use a transistor with low resistance in the conducting state of structure. It is also necessary to select an appropriate topology of the synchronous rectifier circuit with respect to the number of transistors. Very important part of topology is control of MOSFET transistors, which enables the transistor to conduct current from zero voltage UDS. Commutation failure is not acceptable. The paper describes the issue of power supplies for electroplating processes, their activities and various topologies; control and principle of synchronous rectifier. It brings also experimental verification of the synchronous rectifier, efficiency comparison of switching power supply using a synchronous rectifier and a diode rectifier, where body diode of MOSFET transistor is used for rectification.[1]

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2. REQUIREMENTS FOR POWER SUPPLY

All technological processes take place in an environment of galvanic baths of various sizes and designs. Their activities require (with some exceptions) power supplies of small DC voltage with high output currents. In the aspect of required performance we can divide resources for electrochemical applications to several categories. Power supplies with minimal performance (up to 1 kVA) are less important and used for technological processes as degreasing e.g. Medium performance (up to 40 kVA) is typical for the metallization and small refinery links and big performance supplies (from 100 kVA) are used for large refining links and production of chlorine and aluminum.

Supplies specific characteristics depend on the character of electroplating techniques. It is a particular need for low output voltage, very high currents. The fact that the bath is a source of reverse voltage of variable level is important, too. For some technological processes, it is also necessary to allow change the polarity of the output voltage of power supply. Output current with minimal ripple allows achieve superior surface in most cases, ie. homogeneous layer of deposited metal. In the case of minimal current ripple of metalized material surface, liquid products are removed worse and we must remove it with additive surface washing. The optimal value of current ripple is topic of debates for years, but acceptable level of current ripple is set to 2-5% of current average value [1].

3. SYNCHRONOUS RECTIFIER

In synchronous rectifier, diodes are replaced MOSFET transistors. Diodes must be engaged with respect to the fact, that in presence of driving signal in the gate transistor works in the third quadrant of the static output characteristics (Fig. 1).

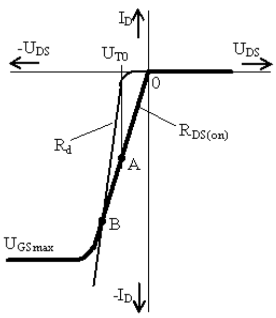

Fig. 1 V-A characteristic of MOSFET transistor and the body diode

In the third quadrant, the body diode is conductive, because it is polarized in forward direction. If the supply output voltage is polarized reverse, transistor works in the first quadrant of its static characteristics and transistor is closed. We can also see that the body diode is in the blocking state. MOSFET transistors are able to conduct current at zero voltage UDS. This is not able in the diode due to its threshold voltage value. Threshold diode voltage in its conductive state causes loss proportional to the product UTH.IF(AV). In synchronous rectification this part of the losses is eliminated. If the transistor is open and operates in the third quadrant of its output characteristics, it can conduct current from the zero voltage without applying the threshold voltage of the body diode. Voltage drop on $R_{DS(on)}$ increases with increasing current; in point A this drop reaches the body diode threshold voltage value, the diode opens and starts to conduct current. In this time, both elements are conductive simultaneously as parallel elements and hence the total resistance of MOSFET transistor is formed by parallel connecting $R_{DS(on)}$ and dynamic resistance R_d of body diode (Fig. 2). Increasing voltage on structure (from zero to the threshold voltage of body diode) has characteristic slope of $R_{DS(on)}$. Next increasing of voltage has characteristic slope of parallel connected $R_{DS(on)}$ and R_d. Values of current depend on a value of voltage drop on transistor and body diode. In point B, both currents are equal. In next increasing of voltage higher current is flowing through diode than through the transistor.[2], [3]

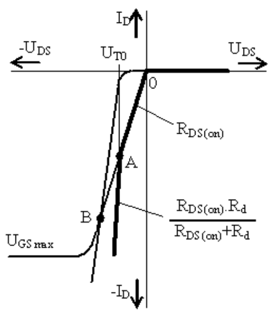

Fig. 2 The resulting output characteristics structure

Power losses of the MOSFET transistor, for voltage drops from zero to the value of body diode threshold voltage, expresses the equation 1; losses from A to B are expressed in equation 2. These losses represent a voltage drop of synchronous rectifier:

$$\Delta P_1 = R_{DS(on)}.I_D^2 \tag{1}$$

where:

$$\Delta P_2 = \frac{R_{DS(on)}.R_d}{R_{DS(on)} + R_d}.I_D^2 \tag{2}$$

The diode is characterized with permanent voltage drop due to its threshold voltage and the voltage drop due to the dynamic resistance R_d. Power losses of diode expresses equation 3:

$$\Delta P_3 = U_{T0}.I_D + R_d.I_D^2 \tag{3}$$

Fig. 3 shows comparison of conduction losses for synchronous and diode rectifier.

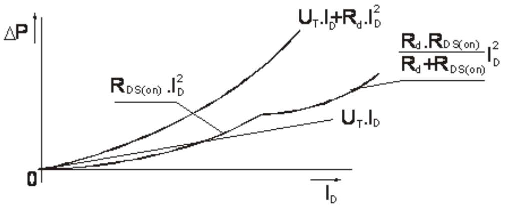

Fig. 3 Comparison of conduction losses

In addition to conduction losses, in semi-conductive structures we can calculate switching losses, control losses and loss in the rectifier commutation. These losses depend on the topology of the rectifier circuit. The energy required for charging and discharging of MOSFET input capacity generates control losses and they are increasing with increasing frequency.

4. CONTROL OF SYNCHRONOUS RECTIFIER

Basic topologies of synchronous rectifiers are derived from conventional. There are two types of control, external control and self-control of synchronous rectifier transistors.

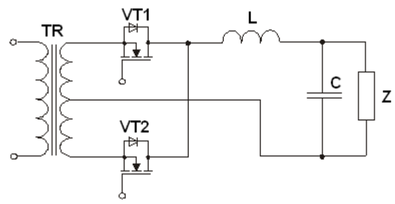

Fig. 4 Control synchronous rectifier

An example of external control is in Fig. 4. Control of synchronous rectifier MOSFET transistor contains control and driver circuit, which generates control signal. We must set precise timing of control signals, which is the most critical point of this work. Timing of control signals can be obtained by two ways. The first is to obtain control data from the primary site of converter, from control circuit of the converter. Galvanic isolation of control signal in the secondary side of converter from the primary one is needed. Precise timing of control signals to the gates of MOSFET is important.

Additional control losses occur in the external control. The advantage of the external control is non-dependency of control signals due to load variations, simple gate protection and particularly accurate timing of control signals.

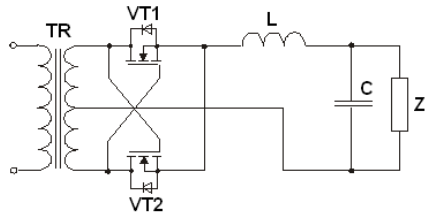

Fig. 5 Self-driven synchronous rectifier

In self-driven synchronous rectifiers voltage from secondary transformer side is directly used for transistor control. The self-driven synchronous rectifier is shown in Fig. 5. With the power supply topology on the primary side of transformer the shape control curves are changing. Certain requirements are placed on the control curve. The voltage levels must be high enough for safe switching of transistors, but not too high because of the security of the gates. Energy for control used to charge the parasitic capacity of MOSFET transistors can be used from the magnetizing or dispersion transformer inductance [4], [5].

5. EXPERIMENTAL VERIFICATION

Experimental verifications were made on full bridge converter shown in fig.6. Parameters of converter with synchronous rectifier are: input voltage 565V, output voltage 15V, output current 500A, switching frequency 17 kHz.

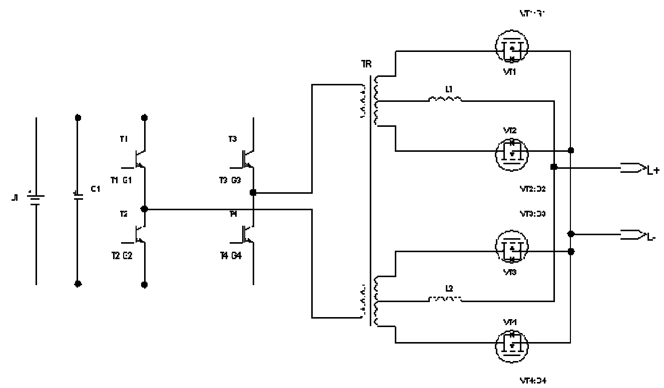

Fig. 6 Full-Bridge converter with synchronous rectifier

For synchronous rectifier switches, one of the newest family of transistors from IR were used. It deals about MOSFET IRFS3004 with these parameters : I_D=240A U_{DS}=40V $R_{DSON(MAX)}$=1,25mW. Driving signals for synchronous rectifier were taken from main control board of full bridge part. These signals were galvanic isolated from primary part of converter, through high frequency driving transformer. As a driver, the new circuit was made, because commercial available circuits are not sufficient for our application due to high value of transistors input capacitance.

Fig. 7 shows driving waveforms during measurement and drain to source voltage of synchronous rectifier transistors. It could be seen, that output voltage was set to 12V at 17 kHz. Driving circuit was design to meet various requirements, one of them was possibility to set up intervals with or without dead time, what is determined by operation of whole system. On fig. 7 operation of synchronous rectifier in mode with dead time is presented. Another advantage of driving circuit is also selectable dead time, which is suitable for various types of transistors.

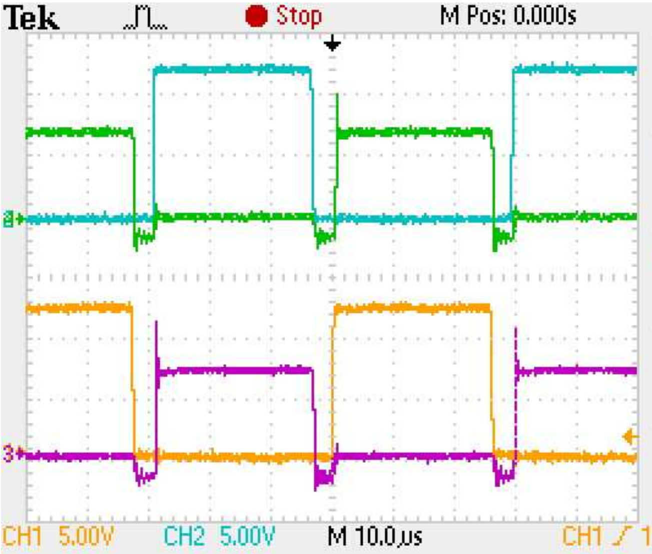

Fig. 7 Waveforms of transistor voltage VT1 and VT2 (CH2-U_{GS1}, CH4-U_{DS1} , CH1-U_{GS2}, CH3-U_{DS2})

Fig. 8 shows dependency of converter's efficiency on output power/current. Input voltage during measurement was 200V. The measurement was made at lower input voltage, due to lack of suitable electronic loads. For comparison of efficiency between diode and synchronous rectifier, is this voltage sufficient. From fig. 8 is clear that synchronous rectifier has better efficiency at the whole range of output power/current.

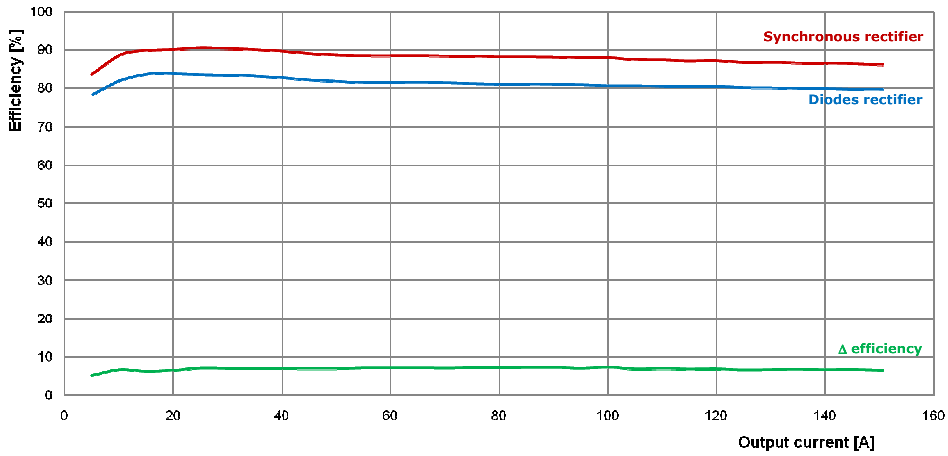

Fig. 8 Comparison of efficiency characteristics

Fig. 9 shows thermal images of devices used in rectifiers. The temperature of diode at 150A load was 101°C, while temperature of MOSFET transistor in synchronous rectifier was 61°C at the same load.

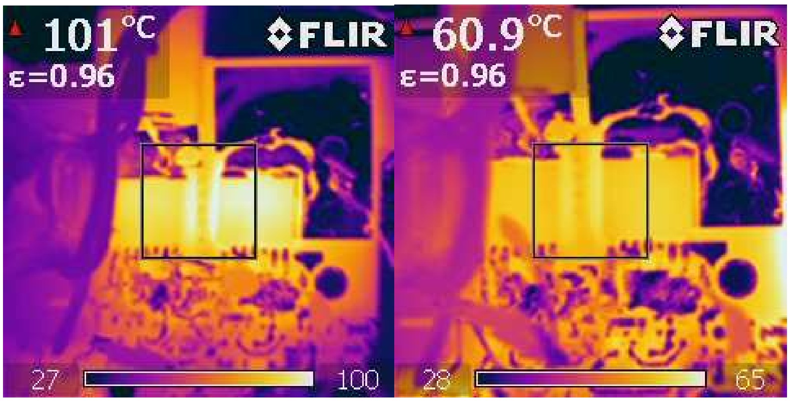

Fig. 9 Thermal image of diode (left) and synchronous rectifier (right)

6. CONCLUSION

The main goal of this experiments was increasing efficiency of switching power supply using synchronous rectifier. Utilization of the synchronous rectifier is advisable for power supplies for electroplating, with switching frequency higher than 20kHz. Increase of efficiency by aprox. 7,3% compared to diode rectifier. Used topology for this synchronous rectifier is suitable for high currents, because the current always flows through only one transistor to reduce the losses. The results of this experiment will help in the design of the source with output current of thousands of amps for electroplating industry.

Acknowledgement

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